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Title: Safeguards by Design Projects Final Report - FY21

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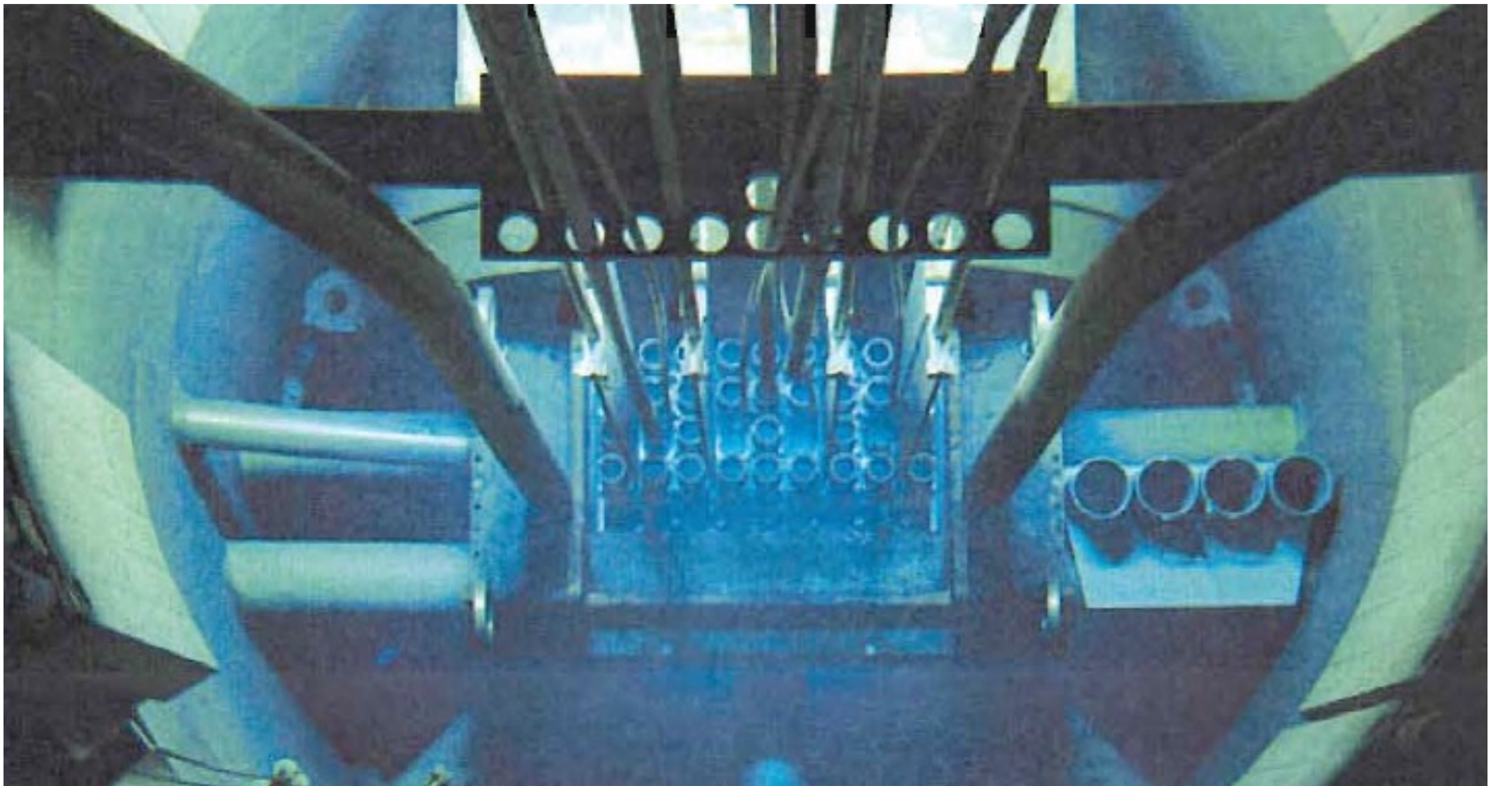

Safeguards by Design Projects Final Report- FY21

University of Rhode Island

University of Texas - Austin

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September 20, 2021
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List of Acronyms

COVID-19	Coronavirus-2019
DOE	U. S. Department of Energy's
HCD	Human Capital Development
IAEA	International Atomic Energy Agency
LANL	Los Alamos National Laboratory
MW	Mega-watt
NETL	Nuclear Engineering Teaching Laboratory
NEUP	Nuclear Engineering University Programs
NNSA	National Nuclear Security Administration
RINSC	Rhode Island Nuclear Science Center
ROUP	Remotely operated underwater platform
TRIGA	Training, Research, Isotopes, General Atomics (Research Reactor)
URI	University of Rhode Island
UT-A	University of Texas at Austin

Safeguards by Design Challenge Final Report- FY20

1. Project Summary

This University Engagement project challenged engineering students at universities, that do not have Bachelor degrees in nuclear engineering but do have research reactors and some nuclear engineering coursework, to incorporate Safeguards by Design concepts into their Senior Capstone Design Project. This University Engagement project was part of the U. S. Department of Energy's (DOE) National Nuclear Security Administration (NNSA), Office of Defense Nuclear Nonproliferation, Office of International Nuclear Safeguards, Next Generation Safeguards Initiative, Human Capital Development: University Engagement Program. This program exposed university students with Mechanical Engineering majors and Nuclear Engineering minors to the concepts of international nuclear safeguards.

In FY21, three teams at the University of Rhode Island and two teams at the University of Texas - Austin participated in researching, designing, building, and testing projects to support international nuclear safeguards measurements or verification. The projects involved engaging in activities at the university's research reactors. All the projects engaged students with prototyping a design and/or tool for application at the Universities' reactor. At the end of the course, most of the students expressed the experience was positive and they learned more about international nuclear safeguards and applying requirements than they had previously encountered.

This school year the projects were further complicated by the COVID-19 pandemic. Both universities had limited in classes on campus, still relying on Zoom classes, and limited direct student/professor interactions. Furthermore, Los Alamos National Laboratory (LANL) greatly restricted travel, therefore making it impossible to visit the students at the end of the semester for the review of their design projects. The final design and review meeting for the projects happened via meetings over the internet. Additionally, the teams did build and test some prototypes but on a very limited capacity and typically from a student's apartment.

2. Merit to Human Capital Development (HCD)

These university challenges directly contributed to the HCD mission by introducing students from the broad engineering field to safeguards concepts and approaches as part of their engineering senior level design course. Unlike nuclear engineering or other safeguards-focusing majors, the students had no knowledge of safeguards, non-proliferation, or the International Atomic Energy Agency (IAEA) before initiating their projects. Using the Senior Capstone Project is a great venue for the students to get hands on experience incorporating safeguards needs into their designs and seeing how those needs interact with the engineering requirements that are more standard. The students not only learn about safeguards, but also learn that they can contribute to the safeguards mission. Nuclear safeguards can only reach its full potential in terms of cost and resource savings if all the different voices during the planning and construction phases of a facility are aware of the requirements and incorporate them in the design phases.

Additionally, LANL has retiree James Sprinkle, who formerly worked in the IAEA Safeguards Division on staff supporting the students, and reviewing design concepts and reports.

Some of these design concepts may eventually merit undergoing the patent process; and or sharing the designs for build and use at other research reactors.

3. FY21 University Engagements:

3.1 University of Rhode Island:

LANL and the University of Rhode Island (URI) are working three projects for the 2020-2021 school year. These projects go over two semesters, so the same team works on the projects for the entire school year. Each project team consists of three to four students. Additionally, the focus for the projects for this school year was using the Rhode Island Nuclear Science Center (RINSC), which houses a General Electric 2 mega-watt (MW), light water cooled, pool type reactor. See Figure 1. The URI Senior Design Course covers two semesters (a full school year).

Figure 1. Photographic showing Rhode Island Nuclear Science Center (RINSC) and the General Electric Research Reactor.[1]

Professors and Staff:

- Prof. Dr. Bahram Nassersharif: *Distinguished University Professor,* University of Rhode Island, Mechanical, Industrial and Systems Engineering Department

- Prof. Cameron Goodwin: *Adjunct Professor,* University of Rhode Island, Mechanical, Industrial and Systems Engineering Department, & Director, Rhode Island Nuclear Science Center

3.2 University of Texas-Austin:

LANL and the University of Texas-Austin (UT-A) worked one project for the fall 2020 and one project for the spring 2021 semester. Both project teams consisted of four students. Additionally, the focus for the project was using the research reactor at the Nuclear Engineering Teaching Laboratory (NETL) located on the J.J. Pickle Research Campus. The reactor is a 1 MW TRIGA (Training, Research, Isotopes, General Atomics) Mark II Research Reactor. See Figure 2. As university's shut down other TRIGA reactors across the country, UT-A accepted fuel from the closing reactors. There is limited history on this fuel, so NETL has a true safeguards need to be able to identify the nuclear material content of the fuel.

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[1] Rhode Island Nuclear Science Center, accessed August 18, 2020 here: http://www.rinsc.ri.gov/ and here: http://www.rinsc.ri.gov/education/

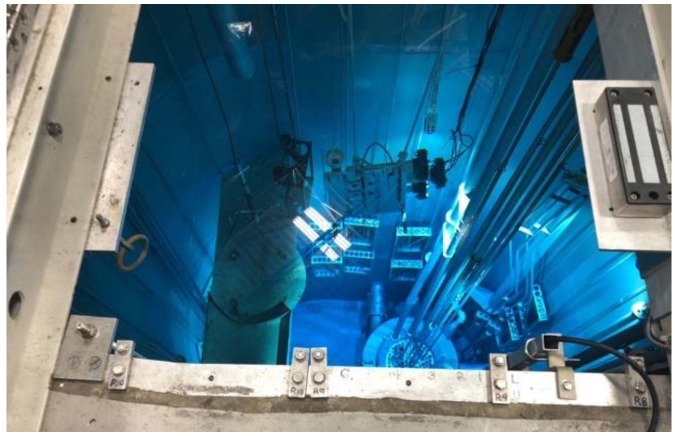

Figure 2. Photographic showing location of UT-A's Nuclear Engineering and Testing Laboratory (NETL) and the inside of the TRIGA Research Reactor.[2]

Professors and Staff:

- Prof. Richard Crawford: *Earl N. & Margaret Brasfield Endowed Faculty Fellowship in Engineering*, University of Texas at Austin, Walker Department of Mechanical Engineering

- Prof. William Charlton: *Director, Nuclear Engineering Teaching Laboratory (NETL)* and *John J. McKetta Energy Professor* in the Nuclear and Radiation Engineering Program, University of Texas at Austin, Department of Mechanical Engineering

4. FY 21 Design Projects

In FY21 LANL completed 3 projects with student teams from URI and 2 projects with student teams from UT-A. See Table 1 for a complete list of FY20 projects.

Table 1. List of University Engagement Projects for FY21

University	Project	Title	# Students
URI	1	Improved Visual Underwater Fuel Inspection	4
URI	2	Improved Fuel Inspection with Gamma-ray Spectroscopy	4
URI	3	Improved Neutron Radiography Capability for Fuel Measurements and Inspections	3
UT-A	4	Improved Neutron Measurements for Nuclear Fuel Confirmation Measurements in a TRIGA Reactor Pool – Fall Semester	4
UT-A	5	Nuclear Fuel Confirmation Measurements for TRIGA Reactor Fuel using Calorimetry – Spring Semester	4
		Total Number of Students	19

LANL has copy of all final reports, presentations, and brochures for student designs.

[2] Picture on left taken from: https://en.wikipedia.org/wiki/J._J._Pickle_Research_Campus

4.1 University of Rhode Island Capstone Design Projects

4.1.1 Capstone Design Project 1: Improved Visual Underwater Inspection of Fuel Elements

Design of an improved remotely operated underwater platform (ROUP) for videography of nuclear fuel elements.

There are routine inspections of nuclear fuel elements at research reactors for safety and safeguards purposes. There are inspections of nuclear fuel assemblies at power reactors before core loading and after removal from core for refueling of the nuclear reactor. Currently at research reactors operators inspect fuel elements manually by multiple operators. One operator removes the fuel element from the core, (during shutdown,) and raises the fuel element to approximately six feet underwater and a second operator takes photographs of the assembly from the pool side. There are several challenges that affect the photographing process; these challenges are optical distortion of the image by the presence of the water medium, surface disturbances caused by the pole holding the assembly, and the normal water circulation in the pool.

Operators would prefer to not have to raise the fuel assembly from its normal depth of approximately 30 feet under water, which would require the lowering of a camera to fuel depth and then photographing and video recordings at a relatively close distance to the fuel element. To accomplish this photography and videorecording would require designing a remotely operated platform and camera to record the imagery.

The goal of this project is to improve on the design from the 2019-2020 Capstone Team. Then build, and test a platform to use photography and videography to support safeguards and nuclear material inventory taking of fuel at the RINSC reactor. The design has the following technical requirements.

- The ROUP platform shall operate underwater to inspect nuclear fuel remotely in pool research reactors at approximate depths of approximately 30 feet.

- The design shall meet international nuclear safeguards requirements and U.S. NRC safety regulations. This project shall build on the concept from the 2019/2020 school year project.

- The underwater rover design shall incorporate a camera with radiation protection (shielding) for still or video photography of fuel element in the pool research reactor to identify fuel element number and inspect fuel element for cracks or other damage.

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4.1.2 Capstone Design Project 2: Improved Fuel Element Inspection with Gamma Spectroscopy

Design of a gamma spectroscopy and isotope identification system compatible with installation on the ROUP designed under project 1.

For the second URI project the design team shall improve on the design from the 2019-2020 school year to be able to take gamma measurements on nuclear fuel to determine nuclear material content for inventory taking of fuel at the RINSC reactor. The design has the following technical requirements.

- The rover shall operate underwater to inspect nuclear fuel remotely in pool research reactors at approximate depths of approximately 30 feet.

- The design shall meet international nuclear safeguards requirements and U.S. NRC safety regulations. This project shall build on the concept from the 2019/2020 school year project.

- The underwater rover design shall incorporate gamma-ray spectroscopy capabilities to interrogate fuel elements for identifying isotopic composition. This will require design of water-proofing the gamma-ray instrument and interfacing with existing detector hardware and software at the Rhode Island Nuclear Science Center (RINSC) to incorporate automated isotopic analysis of fuel elements.

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4.1.3 Capstone Design Project 3: Improved Neutron Radiography Capability for Fuel Measurements and Inspections

Design of an improved collimator for neutron imaging system for the Rhode Nuclear Science Center Reactor.

Neutron radiography is a useful tool for looking at used/spent/irradiated nuclear fuel. This device can find cracks in the fuel rod cladding, additionally with neutron radiography one can evaluate the nuclear material content of the fuel. Currently spent fuel content is a calculation based on reactor operation. Determining reactor operation time and conditions is challenging for research reactors because operators shut on and off reactor more frequently, move fuel around more frequently, and often flip fuel rods for improved performance. Measurements of actual nuclear material content in the fuel rod would support international nuclear safeguards, and improve nuclear material accounting. The task for the students was to design a neutron radiography facility that could be part of the RINSC, for better fuel nuclear material accounting and photographic radiography for fuel inspection to look for defects in the fuel rod cladding.

For the third URI project the design team shall improve on the design from the 2019-2020 school year to be able to design a capability to do neutron radiography and neutron spectroscopy for nuclear material content of fuel. This project may only be a design project and not a build and test project if URI is unable to acquire the necessary hardware for the project. The design has the following technical requirements.

- The improved design of a neutron radiography facility for the Rhode Island Nuclear Science Center that could assist in meeting international nuclear safeguards requirements (inspection and elemental/isotopic analysis of fuel) and will meet NRC safety regulations. The design shall begin with the design from the previous year (2019-2020 school year).

- This design shall improve on previous designs in the areas of neutron beam device, radiation imaging, and conversion to visual band. The work will focus on the analytical and simulation of the facility for use at the Rhode Island Nuclear Science Center (RINSC).

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4.2 University of Texas at Austin Senior Design Project

4.2.1 Senior Design Project 1: Neutron Measurements for Nuclear Fuel Confirmation Measurements in a TRIGA Reactor Pool

Development of a capability to use neutron measurements for nuclear fuel confirmation measurements in a triga reactor pool

It is critical to global security to ensure there is no diversion of nuclear materials from civilian nuclear facilities for military purposes. A system of safeguards can support verifying the completeness and correctness of a State's declaration of their nuclear materials and nuclear activities. Due to the highly variable and adaptable nature of research reactors, the verification of the nuclear material content of nuclear is challenging. For the University of Texas at Austin Nuclear Engineering Teaching Laboratory (NETL) reactor this issue is further complicated by the progeny of its fuel materials. All the fuel used by the NETL came from another research reactor facility, therefore the details of the irradiation profiles of the fuel is unknown. Thus, there is a larger than desirable uncertainty associated with the nuclear material content of the fuel used at the NETL.

Operators typically characterize nuclear fuels by the fuel burnup, irradiation time, cooling time, and initial ^{235}U enrichment. Burnup measures the energy produced by the fuel per unit mass of initial uranium. Knowledge of the characteristics listed above are useful in correlating nuclear material content of the used fuel (specifically ^{235}U and Pu mass). Measurements of several fission product neutron signatures together are useful for extracting knowledge of the fuel. Thus, a system that quantitatively measures neutrons emitted from the TRIGA fuel may provide the ability to characterize the nuclear material content for international nuclear safeguards. The team task was to design a system for measuring used nuclear fuel at the NETL TRIGA reactor, build and demonstrate a prototype system. This project builds upon the project initiated during the Spring 2019 school year. The advanced prototype will be able to make gamma and neutron measurements on the reactor fuel.

The focuses on work from previous designs for fuel measurement systems, specifically the team shall incorporate neutron measuring capabilities in the system designed by the Spring 2020 semester team. The new system shall measure nuclear fuel at the UT-NETL TRIGA reactor. The students will learn engineering design principles, radiation detection, and analysis of measured data for safeguards purposes.

The following are requirements for the design project.

- The research reactor fuel measurement system shall be able to measure the nuclear content of used nuclear fuel at the UT-A Nuclear Engineering Teaching Laboratory (NETL) TRIGA reactor. The system shall meet international nuclear safeguards requirements and U.S. NRC safety regulations.
- The research reactor fuel measurement system will have a neutron measurement capability for measuring irradiated fuel in the reactor pool. The Fall 2020 team shall build upon the work completed by the Spring 2020 team.
- The instrument capability shall undergo a demonstration using fuel in the TRIGA reactor at the UT-Nuclear Engineering Teaching Laboratory.

4.2.2 Senior Design Project 2: Using Calorimetry to Measure Changes in Irradiated Nuclear Fuel in a TRIGA Reactor Pool

Development of a capability to use calorimetry measurements for measuring changes in irradiated nuclear fuel in a TRIGA reactor pool

The project focuses on using calorimetry to measure changes in irradiated nuclear fuel in a TRIGA Research Reactor Pool. The technique of calorimetry assay of nuclear materials involves the measurement of the heat transfer rate released by nuclear fuel. In this project, the students are working with irradiated fuel. The project involves measuring accurately the heat transfer, and from this one can calculate the content of some isotopes present in the nuclear fuel. Therefore, the calorimetry technique can gb useful in accounting for changes in the isotopic composition of fuel rods at research reactors.

5. FY21 Project Teams and Final Deliverables

The Covid-19 pandemic greatly affected all the university teams. The teams had limited support in testing designs and making improvements to their design projects. The teams delivered their final presentations via the internet, either through Skype or WebEx. LANL made no visits in the fall and spring semesters to meet with university teams and support meeting the students for the final project review. Many of the 2020-2021 projects will continue into the new school year, 2021-2022, in order for the design teams to be able to build and test prototypes.

5.1 University of Rhode Island Capstone Design Projects

5.1.1 Capstone Design Project 1: Improved Visual Underwater Inspection of Fuel Elements

The students designed, built and tested a remotely operated underwater platform for inspecting nuclear fuel in pool research reactors to help meet international nuclear safeguards requirements and U.S. NRC safeguards and safety regulations. This project was a continuation of the FY20 project. The current team was improving on the design for fuel inspection. See Figure 3 for a picture of the design team and Figure 4 for a replica of the final design poster.

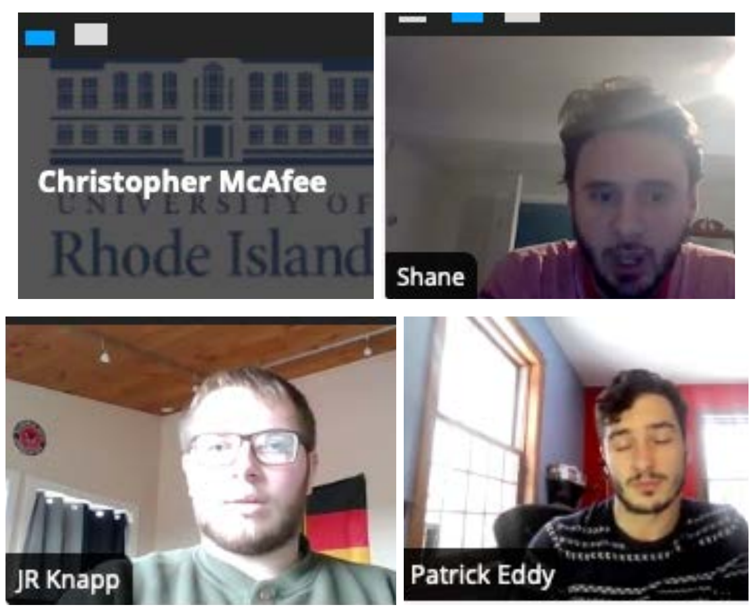

Figure 3. URI Student Team 1 Members: Chris McAfee, Shane Derby, J.R. Knapp, Patrick Eddy.

THINK BIG WE DO™

Mechanical Engineering Capstone Design 2020-2021

JR Knapp – Electrical and Design Engineer
Chris McAfee - Team Leader and Design Engineer
Shane Derby – Operation Engineer
Patrick Eddy – Design Engineer

Team 10 - U.N.I.R.O.D.

Underwater Remotely Controlled Stable Platform

Sponsored By: Los Alamos National Laboratory

Summary

The purpose of this project is to design an underwater remotely controlled stable platform used for inspection of the nuclear fuel elements at the Rhode Island Nuclear Science Center. The design provides a method of fuel element inspection using a remotely operated vehicle (ROV) that will be stable, neutrally buoyant, and suitable for the service environment.

Introduction

The Los Alamos National Laboratory holds the main responsibilities to ensure our nation's security through nuclear deterrence. Their research on nuclear energy and weapons is leading class and our capstone group was tasked to help this research. Nuclear reactors require yearly inspection of the nuclear fuel elements to maintain safety and operation. At the Rhode Island Nuclear Science Center (RINSC) the current method of inspection involves manual operation of a DSLR camera connected to an aluminum rod. This current method provides a safety risk to the operator with minimal opportunity to capture images at certain depths and angles. The advantage of inspecting the nuclear fuel elements with an underwater ROV is the ability to take images at any depth and is a more functional method for inspection of these fuel cells.

Sponsor

Los Alamos National Laboratory is a United States Department of Energy national laboratory. The laboratory's strategic plan reflects U.S. priorities spanning nuclear security, intelligence, defense, emergency response, nonproliferation, counter terrorism, energy security, emerging threats, and environmental management.

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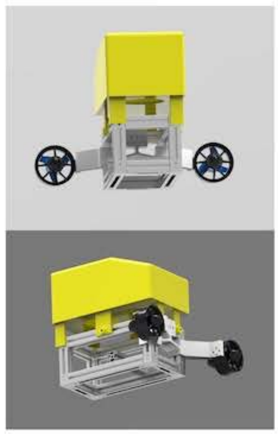
Design Specifications

Product Name	U.N.I.R.O.D.
Service Environment (RINSC Reactor Pool)	400 Grays/hr >6ft away from fuel elements
Total ROV Weight (with camera housing)	20lbs
Dimensions (frame)	12.5" x 6.5" x 5.5"
Materials	Aluminum ABS Plastic Lead
Operating Depth	<25ft
Target Life Cycle	>5yrs
Training	<2hrs
Usage Rate	4x per year
Maintenance	<$100/year
Budget	<$1500
Safety	RINSC Safety Review Document
Special Features	Remote Controller LCD Screen

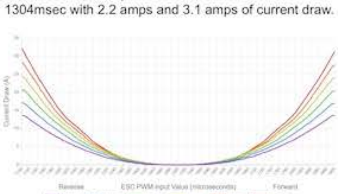
Design



The U.N.I.R.O.D. design draws inspiration from many work class ROV's with the ability for the drone to safely operate within a reactor pool. The design is built around a frame made of extruded aluminum for the camera housing to connect to. The design also incorpt]rates a 3D printed, hollow, waterproof buoyancy system in order to achieve neutral buoyancy. This buoyancy system has a center cutout for the vertical thruster to control motion in the z-direction. The last major design component is the thruster mounts to hold the the x-y lateral thrusters. The thruster mounts hold the BlueRobotics T200 thrusters at a distance from the frame to improve the stability of the drone.

Engineering Analysis

Team 10 used a 3D printed, hollow, and waterproof box in order to achieve neutral buoyancy for the ROV. The buoyancy system was designed to cater to the amount of air volume needed to make the ROV neutrally buoyant. The team used the displacement weights of the ROV and camera housing to calculate their weights in water. This was then used to calculate the total volume of the buoyancy system to be 333.12 cubic inches which the team decided to round up to 350 cubic inches. The BlueRobotics T200 thrusters are ran on a PWM range of 1100 to 1900 microseconds, the 1500 msec signal is considered to be the neutral or off signal. The Z-direction max PWM signal was set at 1800 with a current draw of 8.9 amps and 1100 with a current of 17.03 amps. The two rear thrusters for the X-Y-directional output were set at 1672msec and 1304msec with 2.2 amps and 3.1 amps of current draw.



Current draw vs. PWM Input

Testing

In order to test the thrusters and thruster control the team designed a controller using two joysticks connected to the Arduino microcontroller and breadboard. The telemetry architecture designed by the team makes use of the analog pins on the MCU. The analog signal from the joysticks was mapped to the PWM signal that was sent to the ESC's connected to each T200 thruster. Each joysticks played a different directional role, one to control the vertical thruster and one to control the lateral maneuvering.The lateral control joystick has the ability to run each rear thruster by itself to create a thrust differential and make minor turns and heading changes on the ROV. The testing of the thruster control was successful in order to command actuation from a user input.

Financial Analysis

Project Budget	$1,500
Total Materials Cost	$944.13
Total Accessories Cost	$72
Total Tooling Costs	$0
Total	$1,016.13

The overall cost of the project ended up being much less than the entire budget of $1500. Having access to the student machine shop and the mechatronics lab significantly reduces the tooling costs that the team would have otherwise had to pay for.

Conclusion

Overall, the drone the team designed meets all standards brought to the team from the RINSC and Los Alamos National Laboratory safety and design requirements. The task of making a drone that can withstand the harsh effects of radiation is a difficult task and the team did the best it could with research and development of the drone over the span of the school year. With further testing the drone has all the capabilities that it would need to operate within the nuclear reactor pool.

Further Work

Further work that could be looked into the ROV having the capability to dive down to the bottom of the reactor pool for recoveries of a payload. Furthermore, testing of the buoyancy system would be needed to ensure the use of the ROV in the harsh service environment.

Acknowledgements

Team 10 would like to thank Ms. Carolynn Scherer and Los Alamos National Laboratory for providing the funds for this project. Team 10 would also like to thank Dr. Cameron Goodwin and all of the members at the Rhode Island Nuclear Science Center for taking the time to show the team the reactor. Furthermore, Team 10 would like to thank Dr. Bahram Nassersharif in assisting and guiding the team throughout the semester.

Organized and taught by Professor B. Nassersharif, E-mail: bn@uri.edu, Phone: 401-874-9335

Figure 4. URI Team 1 replica of final poster.

5.1.2 Capstone Design Project 2: Improved Fuel Element Inspection with Gamma Spectroscopy

The students designed a remotely operated underwater platform to remotely inspect nuclear fuel in pool research reactors help meet international nuclear safeguards requirements and U.S. NRC safeguards and safety regulations. This project was a continuation of the FY20 project. The current team was improving on the design for fuel inspection. See Figure 4 for a picture of the design team and Figure 5 for a replica of the final design poster.

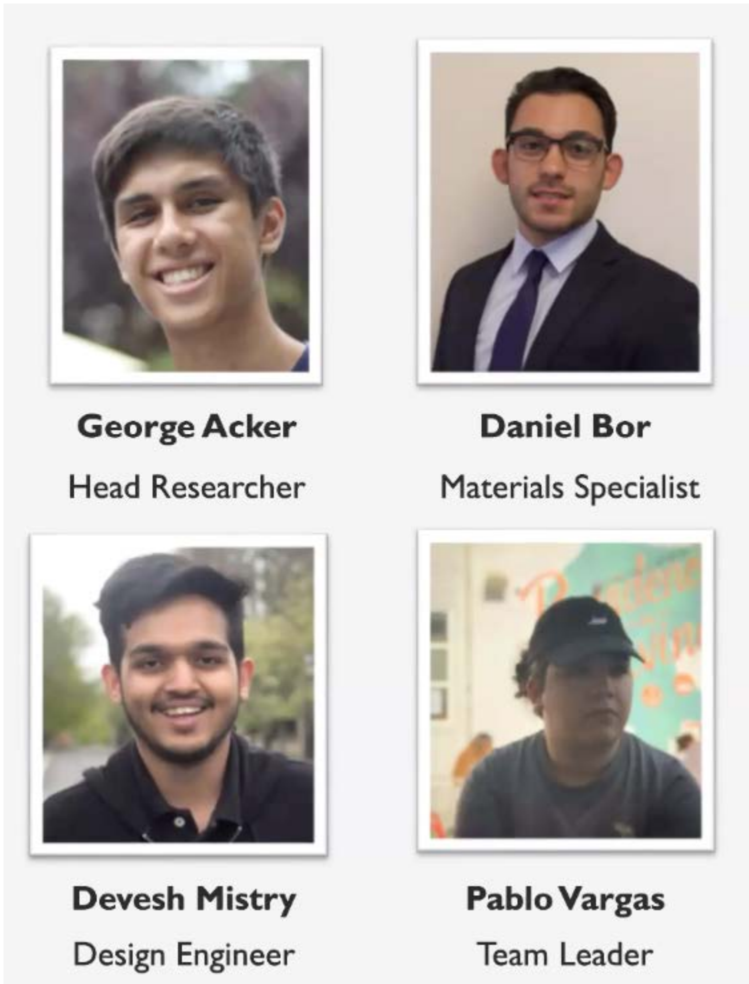


Figure 5. URI Student Team 2 Members for Nuclear Fuel Inspection Device with Gamma Spectroscopy: George Acker, Daniel Bor, Devesh Mistry, and Pablo Vargas.

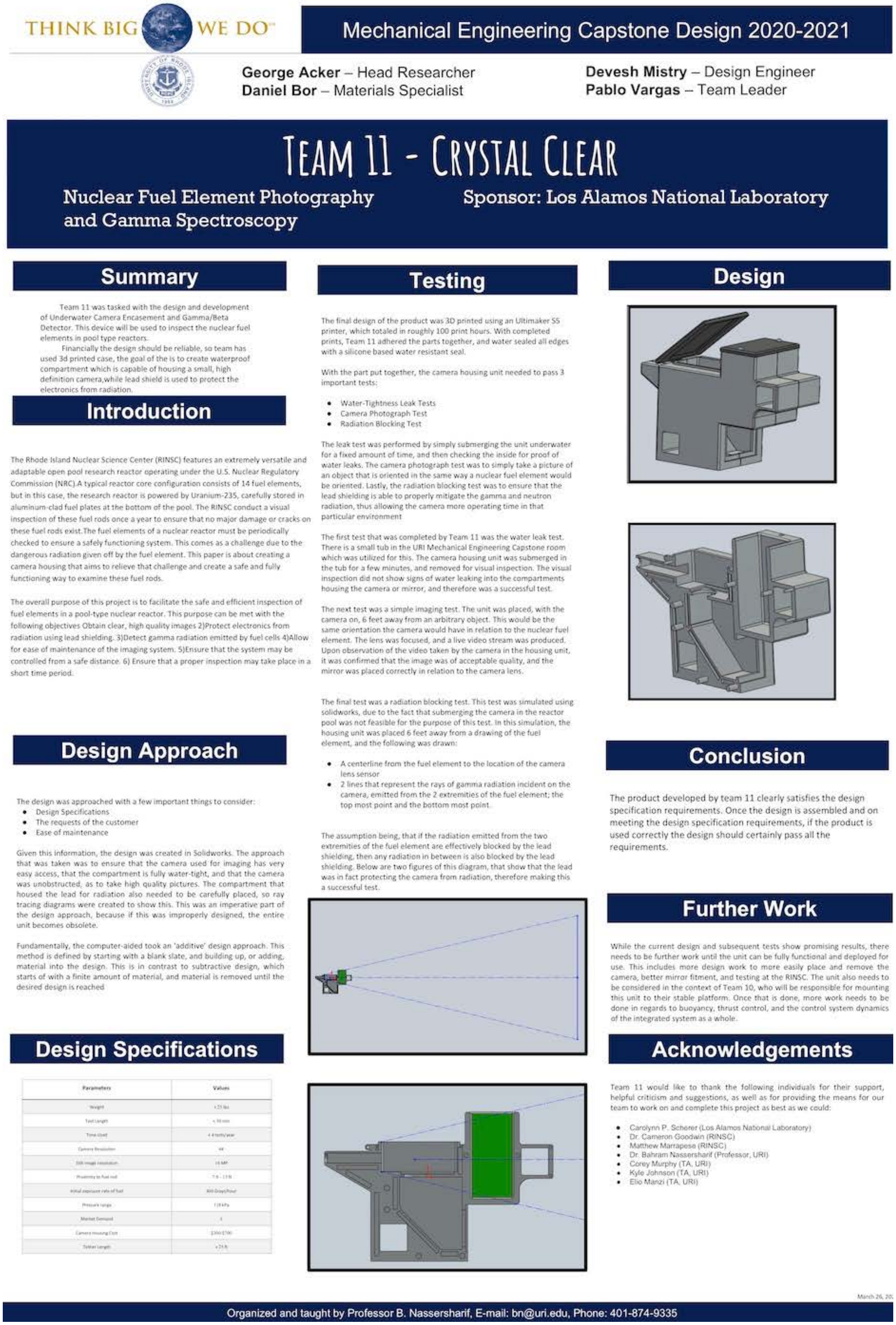


Figure 6. URI Team 2 replica of final poster.

5.1.3 Capstone Design Project 3: Improved Neutron Imaging Facility for Fuel Measurements and Inspections, Focusing on Collimator

The students had a design project, they designed a collimator for the neutron beam facility. The collimator is one of the most critical pieces to the neutron radiography facility. The students narrowed the project down to the collimator so that a sufficient model of this piece could be produced withing the project schedule. The collimator is a large portion of the facility. The team collaborated with LANL, RINSC, and University of Massachusetts at Lowell. After multiple design options the team settled on a linear cylindrical collimator, with construction materials of aluminum, born, concrete and polyethylene components. The team optimized the design and selected a material to fabricate a prototype collimator. Unfortunately, the boron carbide was too expensive, so a prototype was never built.

Figure 7. URI Student Team 3 Members Collimator for Neutron Radiography Facility: Jay Macchia, Sean Babin, and Peter Tillinghast.

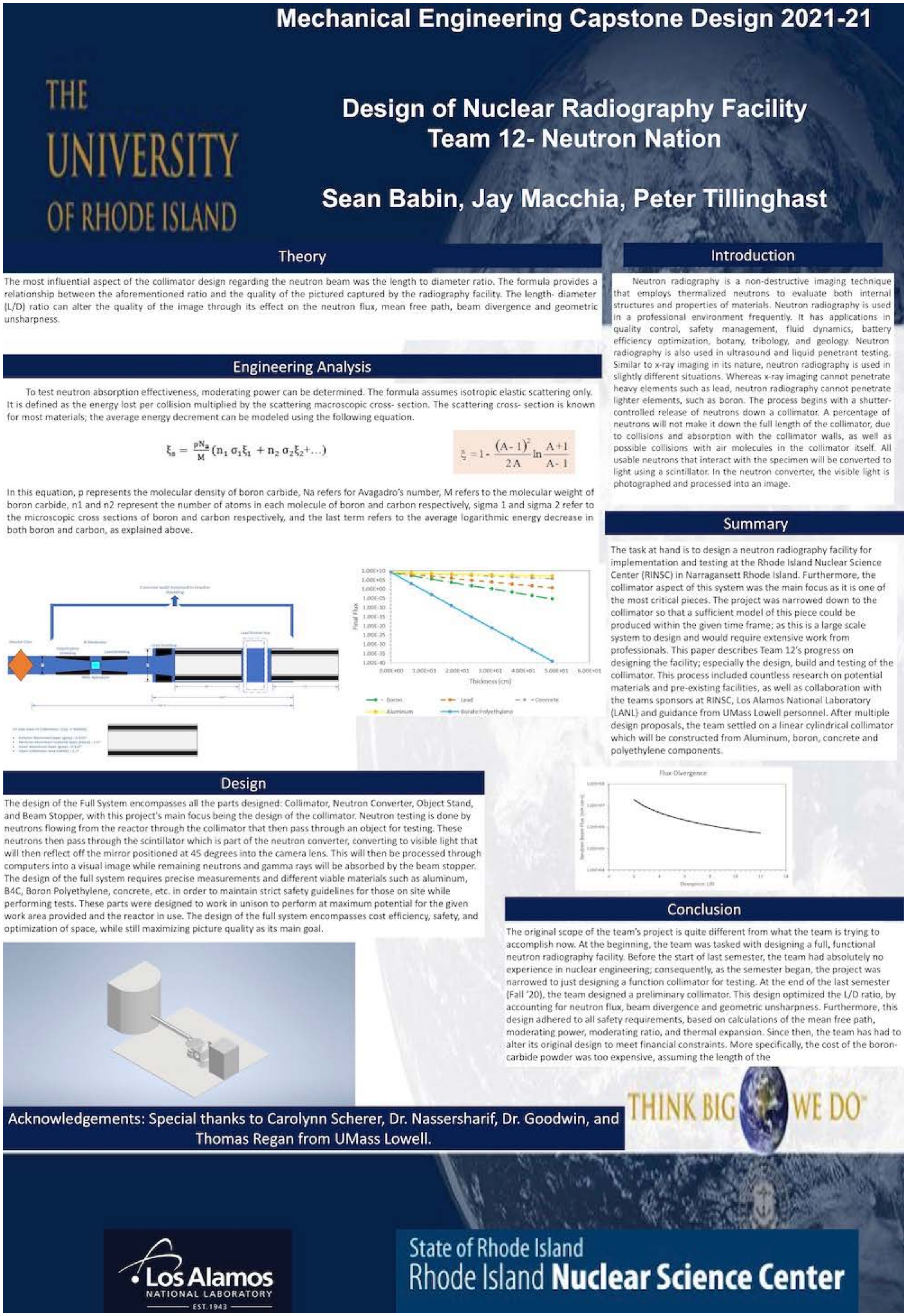


Figure 8. URI Team 3 replica of final poster.

5.2 University of Texas at Austin Senior Design Project

5.2.1 Senior Design Project 1: Neutron Measurements for Nuclear Fuel Confirmation Measurements in a TRIGA Reactor Pool – Fall 2020

Design, simulate, and analyze a portable waterproof neutron detection system to verify the nuclear material content of spent nuclear fuel rods. Below is a excerpt from the Executive Summary of the final report.

Research reactors in the United States lack a simplified way to measure the content of nuclear material in spent fuel contained in nuclear fuel rods. Commercial reactors over the world have safeguards established by the International Atomic Energy Agency (IAEA) to take inventory of the amount of nuclear material in spent fuel, using measurement techniques as their main tool. The IAEA works to confirm the peaceful use of nuclear material. Nuclear research reactors, however, run a less predictable schedule and contain a significantly lower amount of fuel and radioactive material volume. The safeguards in place for research reactors do not currently include fuel measurement techniques. The objective of this project is to design a solution to accurately measure the nuclear material content of fuel rods in a research reactor setting and verify that the measured levels meet those expected. To determine the content of the fuel rods, the team designed a neutron detection system utilizing fission chambers, which collect neutron counts that correlate to the fuel burnup of each rod. The staff at The University of Texas Nuclear Engineering Teaching Laboratory (UT NETL) had previously used a prototype system designed by a past senior design team to take these measurements, but their solution analyzed gamma ray detection while neutron detection is an alternative our system emphasized. Another main objective of this project was to create a system that featured modularity, higher portability, and lower weight than the gamma ray detector system. The project team, with the help of their sponsor and faculty advisor, accomplished this by designing and analyzing a device which uses fission chamber detectors to measure neutron counts from a fuel rod in the pool of the reactor. One major difference between the team's new design and the past design of the UT-NETL gamma measurement detector is that the neutron detection device implements four fission chambers surrounding the testing chamber which ensures structural stability, high measurement efficiency, and accuracy even when the fuel rod is not fixed in place. This system is similar to the gamma ray detection system, both devices undergo submersion in the pool of the reactor to a specified depth. The neutron detectors for this system must be kept dry, so we designed a waterproof housing to encapsulate them, utilizing the same, thoroughly tested waterproofing technique as the previous design team. The neutron detector system is small, lightweight, and easily assembled in a short amount of time, allowing for simplified transportation between research reactor facilities. The system design allows operators to quickly insert individual fuel rods into the detection system. Although the team was unable to prototype the final design due to the COVID-19 pandemic, the team provided both the project sponsor and faculty advisor with a detailed bill of materials, technical files for the components, and manufacturing instructions to assemble the system. After building the system, one can test for waterproofing resistance and effectiveness of measuring neutron counts while submerged. The working model of this neutron measuring system should pose no threats to the health and safety of the operator or nuclear research team.

The University of Texas-Austin Senior Design team consisted of Albert Miller, Harrison Vann. Brandt Glidewell, and Nathan Souder. Figure 9 shows some of the components and other physical features of the neutron detector system

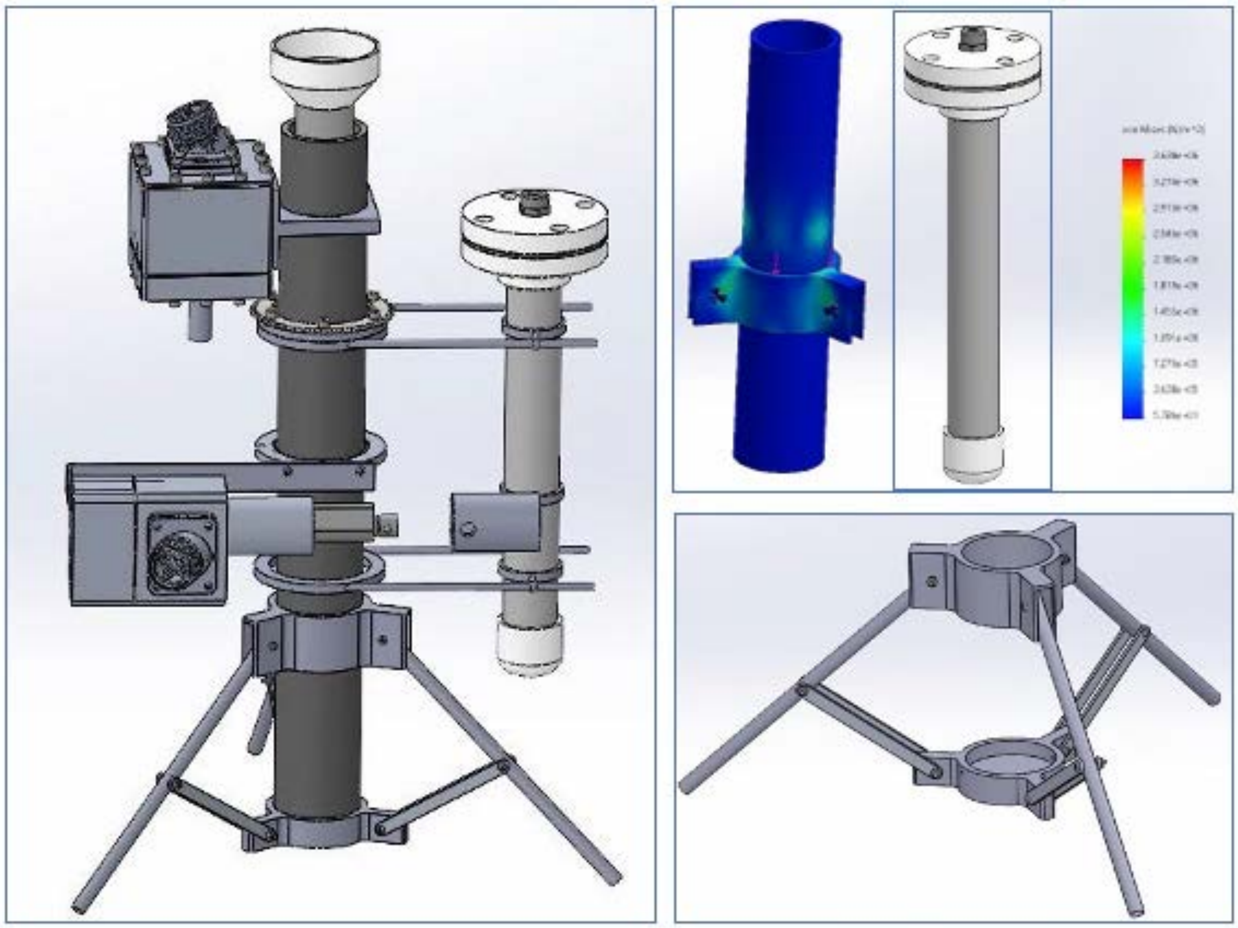


Figure 9. Prototype of neutron detector system, (far left): design of detector system, (top right) stand for fuel rod holder and neutron detector holder, (bottom right): engineering analysis of the neutron detector system, showing stresses.

5.2.1 Senior Design Project 2: Measuring Nuclear Fuel Elements Using a Calorimeter, Spring 2021 Semester

The Nuclear Engineering Teaching Laboratory (NETL) at The University of Texas at Austin hosts a General Atomics TRIGA Mark-II Reactor. NETL's uses the reactor for a variety of research that involves radiation or isotope production. The NETL must adhere to some basic safeguards and security codes to protect the facility and the surrounding community. A safeguard in place is the accounting of all nuclear materials in a facility, ensuring that none of it is diverted by ill-intentioned actors. The project aimed to help NETL with its security goals.

The students designed and prototyped a calorimeter to measure the power released by the fuel rods that taken out of the TRIGA reactor. This measurement can be useful to the staff at NETL, since there are relations between the power released by a fuel rod and the isotopic composition of it. This means that NETL could have an accurate picture of how much nuclear material resides in their fuel rods. If the nuclear material is accounted for, it is easier to spot if any of it is missing.

To design the prototype the students first considered and evaluated the different options. They settled for a passive mode calorimeter; a calorimeter that uses a calibration curve obtained with known power sources to determine the power of the sample being analyzed. They spent some time discussing material limitations since everything had to be compatible with the reactor pool at NETL. They decided to use non-corrosive materials such as aluminum and polyvinyl chloride (PVC), which satisfied the requirements we had for our design. We also worked extensively on the cap design for our calorimeter and did numerous design iterations with this particular component. Our final caps use an O-ring fit to ensure that the calorimeter chamber is sealed off from the surroundings. The T-type thermocouple was chosen based on the expected temperature range and the sensitivity that we required. Lastly, we chose a cartridge heater controlled by a direct current (DC) power supply as our known power source to construct the calibration curve.

After speaking with the staff at NETL, we think there are a few key areas that future teams can improve on our design. These include checking if our prototype has enough thermal insulation between the inner chamber and the environment as well as implementing a servo mode calorimeter to complement the fuel rod power measurement.

See Figure 10 for a photo of the University of Texas-Austin Senior Design team. Figure 11 shows some of the components and other physical features of the neutron detector system

Figure 10. University of Texas-Austin Student Team 2, Lorenzo Castelli, Nicholas Gilbert, Ignacio Ranieri, and Ahmad Zakka.

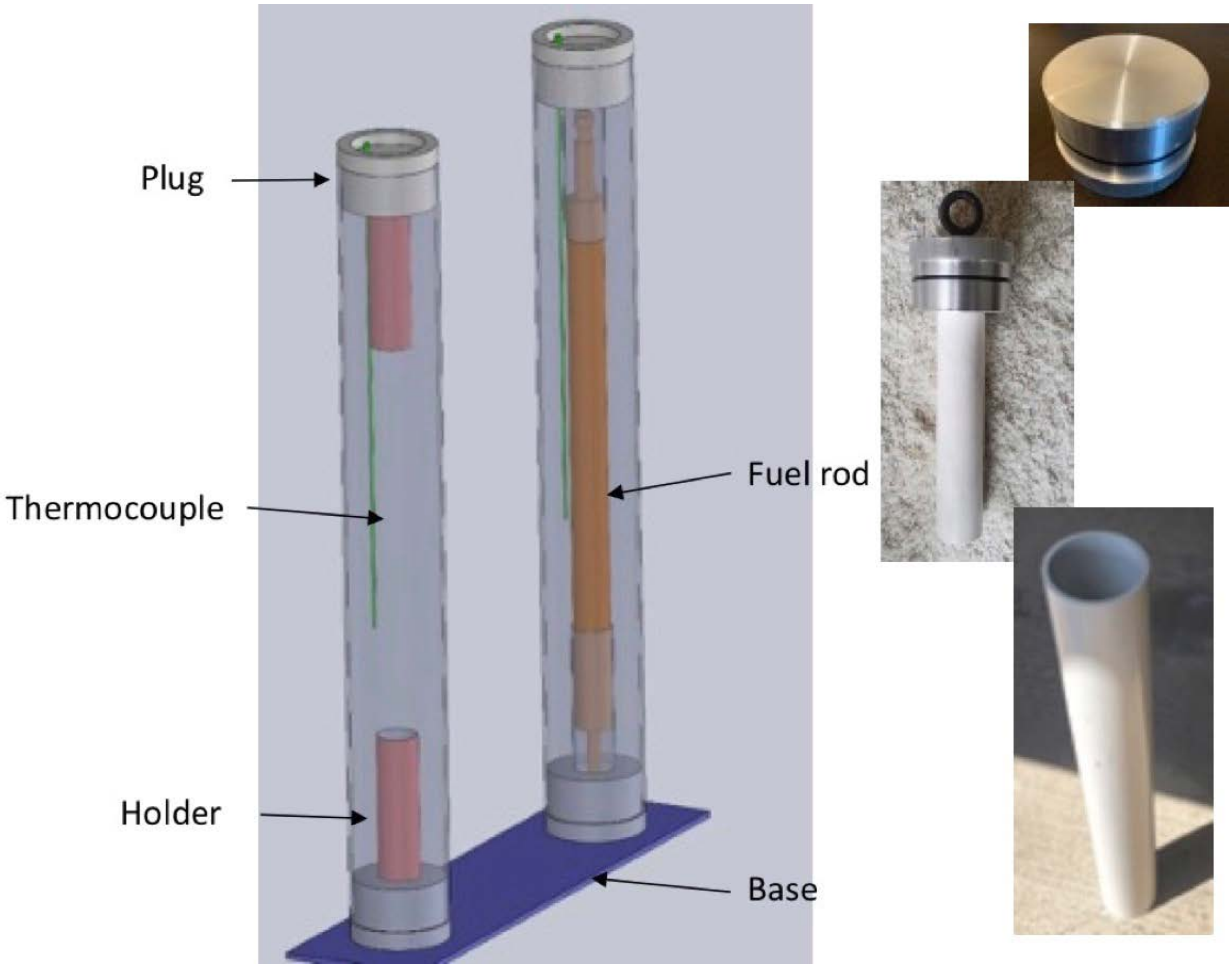


Figure 11. Prototype of neutron detector system, far left: fuel rod holder and neutron detector holder, middle: conceptual design of the neutron detector system, far right top: sealing flange for neutron detects for waterproof seal, and collar to hold fuel rod.

6. FY20 Additional Interactions and Outcomes

6.1 University of Rhode Island

6.1.1 LANL Presentations with URI

Carolynn Scherer presented the student projects with Professor Nassersharif on October 29, 2020; this presentation also covered the application of the 3 Capstone Projects to international nuclear safeguards. Carolynn met with all the students on the 3 design teams, reviewed their projects, helped with direction and guidance during the school year. These interactions were via Zoom.

6.1.2 URI Fall Semester

Carolynn attended the final design reviews at URI in December 8, 2020 via Zoom.

6.1.3 URI Spring Semester

Carolynn attended the final presentations for the student work on April 23, 2021. All presentations at URI were via Zoom.

6.2 University of Texas – Austin

6.2.1 UT-A Fall Semester

LANL met with the UT-A fall students and attended the final presentation on November 16, 2020. The meeting was via Zoom.

6.2.2 UT-A Spring Semester

LANL met with UT-A spring semester students regularly during the semester. There were 2 special WebEx events where the students had a chance to interact with LANL's Dr. Mark Croce, an expert in calorimetry and application to nuclear material measurements; additionally, he also covered microcalorimetry.

Carolynn attended the final student presentation on April 23, 2021.

6.3 Project Overview via the Web

6.3.1 LANL Highlight of Project on LANL Homepage May 27, 2021

LANL highlighted the NA-24.1 HCD, University Engagement Program on LANL's homepage on May 27, 2021. The article's title was "Engineering students take Lab's design challenge to thwart illicitly manufactured nuclear weapons". The link is at: https://int.lanl.gov/news/news_stories/2021/may/0527-engineering-students.shtml. See Figure 12 for a snapshot of the website.

Some highlights from the UT-A spring 2021 semester students are below and their pictures are in Figure 10.

- "This project allowed me to retreat from my comfort zone and explore a new and exciting field of engineering. I also enjoyed being able to turn our design to reality and actually being able to test our idea." Ahmad Zakka, UT-A, 2021 spring participant
- "This project was an excellent culmination of the tools and knowledge I had accumulated at UT Austin. While challenging, it offered me the opportunity to learn more about the field of nuclear engineering and see the design progress to completion, which was very rewarding." Nicholas Gilbert, UT-A, 2021 spring participant
- "I really enjoyed learning about the background behind this project and its application. Nuclear nonproliferation is a very fascinating topic, and it was a pleasure to learn about it from experts at Los Alamos National Laboratory. I also really enjoyed the testing stage of our prototype since all of our different components came together at that point." Lorenzo Castelli, UT-A, 2021 spring participant

LANLInside

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Engineering students take Lab's design challenge to thwart illicitly manufactured nuclear weapons

University engagement flourishes in virtual environment despite pandemic

For the past five years, the Human Capital Development (HCD) Program within the Department of Energy–National Nuclear Security Administration's (DOE/NNSA's) Office of International Nuclear Safeguards has sponsored an effort at Los Alamos National Laboratory to bring together experts in international nuclear safeguards and university students majoring in mechanical engineering. The idea is to expose such students to the realm of international nuclear safeguards, which are designed to ensure that nuclear material and facilities are not used to illicitly manufacture nuclear weapons.

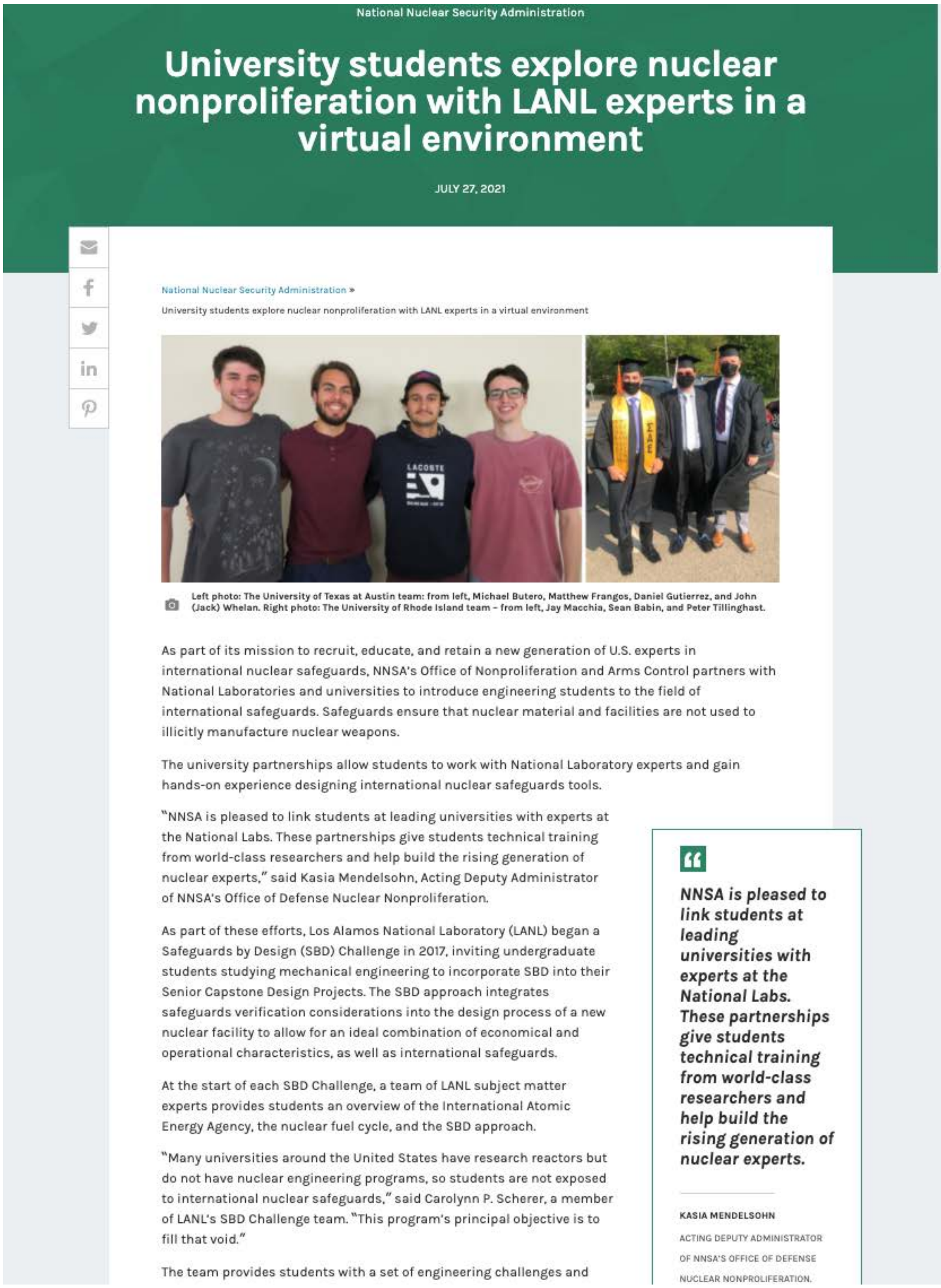
"There are many engineering programs at universities around the United States," explains **Carolynn P. Scherer** of the Systems Design and Analysis Group (NEN-5), who has been at the Laboratory for more than 33 years. "Some educational institutions with research reactors do not have nuclear engineering programs, so students only take 1–3 courses related to nuclear engineering training, and therefore are not exposed to international nuclear safeguards. This program's principal objective is to fill that void by exposing interested students to International Atomic Energy Agency (IAEA) safeguards, which supports deterring the spread of nuclear weapons by the early detection of the misuse of nuclear material."

Students prepare to test their measurement system in the reactor pool.

Figure 12.Snapshot of first page of LANL website featuring University Engagement Project..

6.3.2 NNSA Highlight of Project on LANL Homepage July 27, 2021

NNSA highlighted the student project on the NNSA website on July 27, 2021. The article was "University students explore nuclear nonproliferation with LANL experts in a virtual environment. The link is: https://www.energy.gov/nnsa/articles/university-students-explore-nuclear-nonproliferation-lanl-experts-virtual-environment. See Figure 13 for a snapshot of the website.



National Nuclear Security Administration

University students explore nuclear nonproliferation with LANL experts in a virtual environment

JULY 27, 2021

National Nuclear Security Administration »
University students explore nuclear nonproliferation with LANL experts in a virtual environment

Left photo: The University of Texas at Austin team: from left, Michael Butero, Matthew Frangos, Daniel Gutierrez, and John (Jack) Whelan. Right photo: The University of Rhode Island team – from left, Jay Macchia, Sean Babin, and Peter Tillinghast.

As part of its mission to recruit, educate, and retain a new generation of U.S. experts in international nuclear safeguards, NNSA's Office of Nonproliferation and Arms Control partners with National Laboratories and universities to introduce engineering students to the field of international safeguards. Safeguards ensure that nuclear material and facilities are not used to illicitly manufacture nuclear weapons.

The university partnerships allow students to work with National Laboratory experts and gain hands-on experience designing international nuclear safeguards tools.

"NNSA is pleased to link students at leading universities with experts at the National Labs. These partnerships give students technical training from world-class researchers and help build the rising generation of nuclear experts," said Kasia Mendelsohn, Acting Deputy Administrator of NNSA's Office of Defense Nuclear Nonproliferation.

As part of these efforts, Los Alamos National Laboratory (LANL) began a Safeguards by Design (SBD) Challenge in 2017, inviting undergraduate students studying mechanical engineering to incorporate SBD into their Senior Capstone Design Projects. The SBD approach integrates safeguards verification considerations into the design process of a new nuclear facility to allow for an ideal combination of economical and operational characteristics, as well as international safeguards.

At the start of each SBD Challenge, a team of LANL subject matter experts provides students an overview of the International Atomic Energy Agency, the nuclear fuel cycle, and the SBD approach.

"Many universities around the United States have research reactors but do not have nuclear engineering programs, so students are not exposed to international nuclear safeguards," said Carolynn P. Scherer, a member of LANL's SBD Challenge team. "This program's principal objective is to fill that void."

The team provides students with a set of engineering challenges and

NNSA is pleased to link students at leading universities with experts at the National Labs. These partnerships give students technical training from world-class researchers and help build the rising generation of nuclear experts.

KASIA MENDELSOHN
ACTING DEPUTY ADMINISTRATOR OF NNSA'S OFFICE OF DEFENSE NUCLEAR NONPROLIFERATION.

Figure 13. Picture showing top part of NNSA Website image.

7. FY22 Capstone and Senior Design Projects

LANL has the contracting process underway to cover projects for the 2021-2022 school year at the URI. The Capstone Design class at URI runs for 2 semesters. LANL is also placing contracts to cover 2-3 Senior Design projects at the UT-A to cover a project for the fall 2021 semester, spring 2022 semester, and maybe the summer 2023 semester. See Table 2 for FY22 plans for senior projects.

Table 2. List of University Engagement Projects for FY22

University	Project	Title	# Students
URI	1	Improved Underwater Rover for Fuel Inspections	4
URI	2	Improved Neutron Radiography Facility Design	4
URI	3	New: Detector Array for Source Mapping	4
UTA	4	Improved Calorimetry Measurements for Measuring Changes in Nuclear Fuel Content of Fuel in a TRIGA Reactor Pool – Fall Semester	4*
UTA	5	Advancements in Calorimetry Measurements of Nuclear Fuel – Spring Semester	4
		Potential Number of Students	20

*Students already assigned

Additionally, LANL typically gives a lecture on IAEA safeguards to a class at URI, so we engage with more students. LANL typically gives a overview lecture to students on the design team at UT-A.

7.1 University of Rhode Island

The plan for the 2021-2022 school year is to support 3 capstone projects at the URI. Two projects will be a continuation of projects from the previous school year, with the third project being totally new for FY22.

LANL staff, Christy Ruggiero, Philip Lafreniere, and Carolynn Scherer along with Professor Nassersharif presented the three projects to students in the Mechanical Engineering Capstone Design Course. The presentation was on September 14, 2021 via Zoom. Professor Nassersharif will select the student design teams toward the end of September, and give the students the LANL contacts for them to reach out.

7.1.1 URI Capstone Design Project 1: Improved Underwater Rover for Fuel Inspection

For the first URI project the design team shall improve on the design from the 2021-2022 school year to be able to use photography and videography to support safeguards and nuclear material inventory taking of fuel at the RINSC reactor. The design has the following technical requirements. The Rover has the following design requirements: The underwater rover shall incorporate motors for 3-dimensional operation and a camera with radiation protection (shielding) for still or video photography of fuel elements in the pool research reactor to identify fuel element number and inspect fuel elements for cracks or other damage at the Rhode Island Nuclear Science Center (RINSC). The rover shall operate underwater to inspect nuclear fuel remotely in pool research reactors at approximate depths of approximately 30 feet. This is the continuation of 2 projects from the academic year 2020-2021.

7.1.2 URI Capstone Design Project 2: Improved Neutron Radiography Facility Design

For the second URI project the design team shall improve on the design from the 2020-2021 school year to be able to design a capability to do neutron radiography and neutron spectroscopy for nuclear material content of fuel. This project may only be a design project and not a build and test project if URI is unable to acquire the necessary hardware for the project. This project has the following requirements: The neutron collimator for the neutron radiography facility at the RINSC will build from work completed during the 2020-2021 school year. The requirements will be to improve the collimator design from the 2020-2021 school year, then build and test the new design.

7.1.3 URI Capstone Design Project 3: Detector Array for Source Mapping

For the third URI project the design team will work on a new project, designing, building and testing a neutron detector system for measuring fuel composition of fuel at the RINSC, which may include high-assay low enriched uranium (HALEU). The requirements for this project are to design the process and software to employ a series of detectors (possibly a He-3 array) to map a sizeable radioactive element's radiation profile and composition (such as a fuel element). This project will require the development of software. The concept will require interfacing of the neutron detector hardware with software for making radiation measurements at the RINSC.

7.2 University of Texas - Austin

The plan for the 2021-2022 school year is to support 2 to 3 senior design projects at UT-A. The UT-A Senior Design Projects are one semester, and do not cover the entire school year. LANL submitted Statement of Work for contracting for the Fall and Spring semester. LANL staff is working with the procurement office to get the contract in place as soon as possible.

7.2.1 UTA Senior Design Project 1: Improved Calorimeter for Measuring Changes in Nuclear Fuel Content for Fuel in a TRIGA Reactor Pool – Fall Semester

The fall project will be a continuation of the project from the spring 2021 semester, with the expectation of improvements in the design, and the actual prototyping testing of the designs. The design uses calorimetry to assay changes in composition in irradiated research reactor fuel. The team shall work advance the design of the previous semester for the fuel measurement system. The new system shall measure nuclear fuel at the UT-NETL TRIGA reactor. The students will learn engineering design principles, radiation detection, and analysis of measured data for safeguards purposes. The project has the following requirements: The calorimeter shall be able to measure the heat output of nuclear fuel from the TRIGA reactor to help identify the nuclear material content of the fuel, or change in nuclear material content after irradiation. This project will build upon work begun in the Spring 2021 semester.

LANL already has the fall team assigned an had one WebEx with students on September 8, 2021. See Figure 14 for a snapshot during the WebEx meeting.

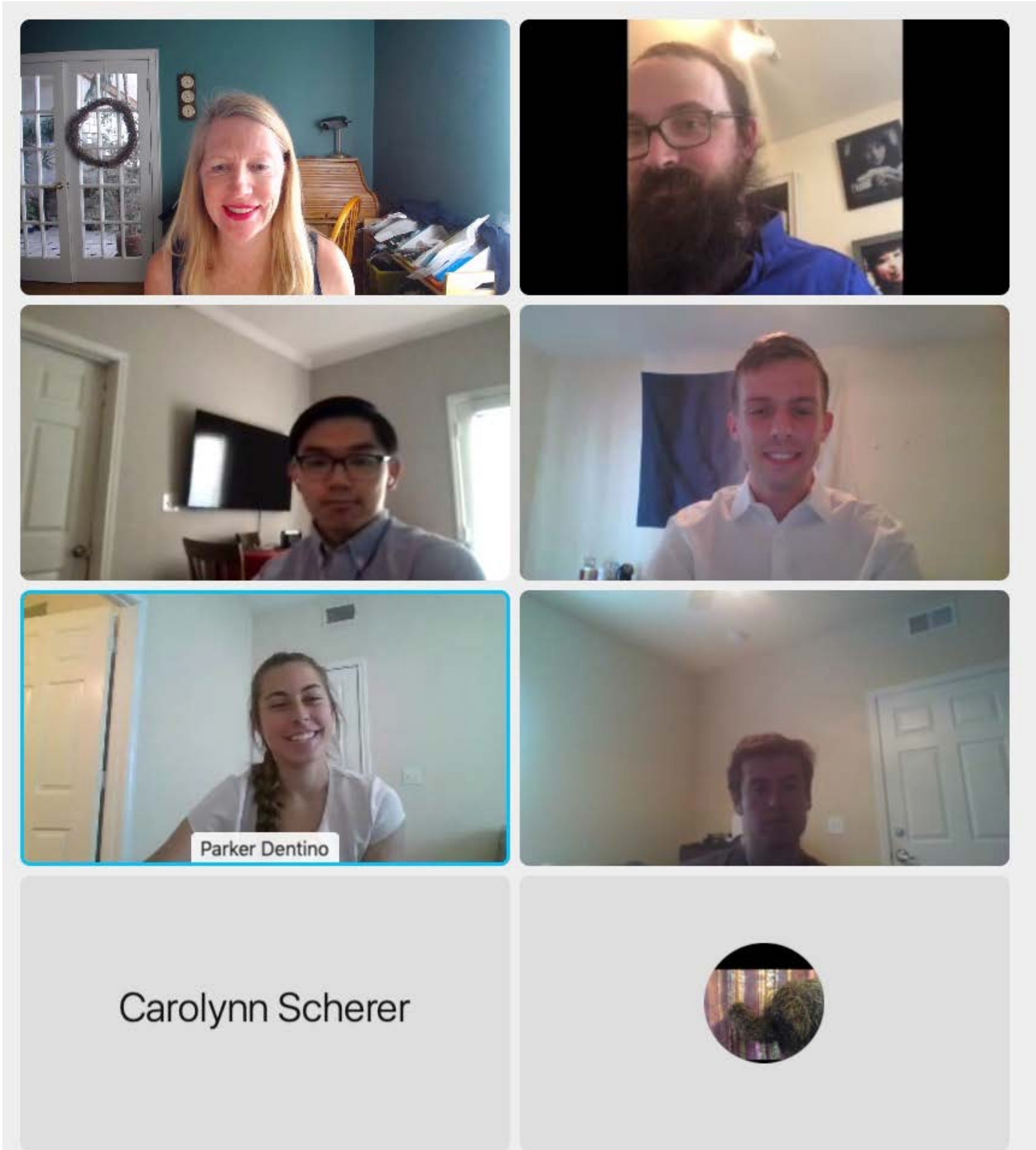


Figure 14. Fall 2021 UT-A calorimeter design team and LANL staff. Top Row: Carolynn Scherer and Philip Lafreniere (LANL). Second and third row UT-A students:Choonggao Lee, John Ketterer, Parker Dentino, and Salvador Chavarria. And LANL staff on the bottom: Christy Ruggiero.

7.2.2 UTA Senior Design Project 2: Improved Calorimeter for Measuring Changes in Nuclear Fuel Content for Fuel in a TRIGA Reactor Pool – Spring Semester

The spring 2022 team will design improvements, build and test a new calorimeter taking into consideration the work from the fall semester 2021. The project has the following requirements: The calorimeter shall be able to measure the heat output of nuclear fuel from the TRIGA reactor to help identify the nuclear material content of the fuel, or change in nuclear material content after irradiation. This project will build upon work completed in the Fall 2021 semester.

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